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Innovative Approach in the Stabilisation of Coastal Slopes

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Abstract

Coastal slope instability poses a risk to life and material property and is of great concern in times of climate change posing challenges as communities seek to adapt and ensure resilience. This paper presents two case studies of coastal slope stabilisation efforts from Scotland and reflects the growing difficultly faced by coastal communities who value intervention but are limited by uncertain ownership, funding and access to expertise. In both cases the slopes are owned by private charities with no power of authorisation or means of procuring stabilisation works to protect the adjacent communities. The engineering solutions included an innovative eco-engineering component where vegetation was used to perform an engineering function. Based on the experience with these projects, we advocate this sustainable technique supported by the evidence from monitoring and testing. The case studies emphasise the importance of engaging with the community as a means to achieving acceptance for a workable solution as well as participation in its long term development. Another significant observation was the contribution played by establishing a learning culture which is supported through inter and intra project knowledge transfer deemed necessary to promote the necessary double loop learning evident in these projects.

Keywords

Sustainability, Slopes – stabilization, Knowledge management, Coastal engineering, Geotechnical engineering

1. Introduction

The significant and lasting change in the statistical distribution of weather patterns over long- and short-term manifesting as a climate change (IPCC, 2013) affects all structures especially the ones on the interface between air, soil, and water such as the coastal slopes (e.g. natural or engineered; Meyer et al 2010). The design and management of these structures is traditionally based on less likely, detrimental, assumed climate characteristics that, if they happen, will bring relatively insignificant change in terms of affecting the stability of the structure.

The stability of coastal slopes, in general, depends on the spatial and temporal distribution of the weather patterns, especially rainfall and wave action which are often triggering soil mass wasting in terms of erosion and landslips (The Scottish Executive, 2005; Minder et al. 2009). In order to minimise the risk to life and property on and near coastal slopes, the potential long and short term impacts of climate change should be taken into account when developing the design for stability and long-term management. Despite this, only a few theoretical frameworks have been reported in the literature (e.g. Iverson 2000; Wong et al. 2004) that account for erosion and landslides as the most frequent forms of mass wasting on slopes. These are based on the analysis of historic events and systematic data collection in order to predict future behaviours, but significantly lack focus on coastal slopes. Currently, communities are not engaged in this activity short of reporting any dramatic instability to the local authority or land owner. This limits the ability of communities to take an interest in the slope beyond the impact of catastrophic events (failure) and limits the opportunities for assessing the risks and development of preventive measures against slope instability.

In the current financial climate when the engineers and managers are tasked with providing ‘more for less’ or ‘value for money’, the main concern encompasses not only the traditional concern for slope stability (Transport Scotland, 2008) but the wider question how society and the affected communities value the slope and its stability as this has a significant impact on the sustainability and resilience of the design and management plan (Mickovski, 2014b). As competition increases for public funds, a case is required for intervention which is viewed in the interests of the tax payer. This ultimately leaves a growing number of communities who value the stability of the slope slopes to seek finance independently. This also raises equity concerns with many communities suffering from being voiceless and unable to access and leverage funds. If communities who value the stability of their slope are to deliver stabilisation through intervention, it is apparent that they need to access knowledge and expertise to help establish solutions both engineered and natural which represent best value, are affordable and in the wider context respect the principles of sustainability.

If innovative slope stabilisation solutions are to be considered within the very limited budgets available for stabilisation, there is a need to maximise the learning from the past projects and balance it against an accurate assessment of risks. The shift towards this thinking has been reflected in the last decade by the inclusion of risk management within the strategic planning framework within which slope stabilisation projects are considered. Although not reflected by its own framework, the introduction of the Climate Change Mitigation Directive, Natural Disaster Risk Management, Shoreline Management Plans (SMPs), Catchment Flood Plans (CFMPs), and Flood and Coastal Risk Management (FCRM) Strategies have set a context for a holistic approach to minimise coastal slope risks and enhance resilience. The inclusion of learning from the past has only been tacitly considered in the above codes of practice.

Apart from the financial aspects such as the available budget, projects are required to increasingly consider both social aspects such as public participation, risk, and social resilience and environmental aspects closely connected to climate change such as whole life costing and carbon footprint. Current local, national, and trans-national strategic planning strategies seek to promote a cultural change and target investment through a proactive and inclusive approach which pulls stakeholders together to promote dialogue between the strategic level (policy makers, regulators and funders), project teams and local communities (McFadden et al., 2009). Such an approach to coastal slope management has the potential to move beyond the dominant learning style which is single loop and to instead promote a more reflective approach promoting double loop learning (Voss and Wanger, 2010). Double-loop learning entails the modification of goals or decision-making rules in the light of experience, where the first loop uses the goals or decision-making rules and the second loop enables their modification taking into account the changes in the surroundings (Argyris, 1991). This widens the evidence base for design and management (Astley-Reid, 2013; Thomson et al. 2014), promoting mediation and transparency. This approach also permits the local system to question and share their learnt experiences and ultimately enhance the ability to respond to complex briefs within constrained budgets. Astley-Reid et al. (2013) explored the potential presented for Community-led Flood and Coastal Management projects demonstrating the potential of local leadership and their access to receiving grants from UK and Scottish Government's. This culture is advocated to promote innovation and avoid over-engineered projects which are costly and disproportionate and instead support solutions which are accepted and sensitive to local needs (Schmidt-Thome and Schmidt-Thome, 2007). With already restricted finances available for coastal stabilisation projects, the situation is exacerbated by the challenge of raising finance for the increasing instance of contested spaces where land and risk ownership remains unclear. For coastal communities there is a need to ensure that opportunities are provided between projects, enabling innovative solutions to be found without always having to reinvent the wheel or spending limited budgets on expensive consultants. It is also necessary that communities are informed of the options and implications of intervention but also of the decision to allow the slope to fail. With limited finance available for intervention, it is possible the best value solution may be to sacrifice the existing property and infrastructure. Communities require the knowledge and expertise to be able to make informed decisions as well as an environment for dialogue and mediation.

This study, through case study analysis, aims to demonstrate the current coastal slope engineering and management strategies in Scotland by investigating the past interventions. Through qualitative research, this study aims to explore whether promoting a wider community approach has helped promote a change in perspective in terms of the interplay of the three sustainability pillars (social, economic and environmental) in decisions taken and the degree of participation in the long term future of the slope. The innovative approach of using eco-engineering techniques for stabilisation and management of coastal slopes is analysed in the light of risk, sustainability, and resilience, as well as stakeholder engagement, innovation, and double-loop learning. The case studies seek to inform how communities with contested spaces can learn from other projects with a view to overcoming barriers linked to funding, inability to draw on expert knowledge and apathy beyond a catastrophic event. A stabilisation and management framework in the context of risk and learning is proposed drawing attention to the use of double loop learning in the development of innovative strategies for design and management of coastal slopes in a changing climate where ownership, community engagement and funding availability are the most important factors which shape the potential for innovation.

2. Methodology

To outline the types of problem associated with the management of the coastal slopes in Scotland, we used a case study approach to establish an understanding of current practice. Comparing and critically analysing two case studies within a similar locality, climate and topography; experiencing similar instability problems, shared planning regulations, local culture and many of the same stakeholders. This approach allowed us to make an empirical inquiry analysing engineering, managerial, and social concepts and phenomena in their "real-life context" (Yin, 1994). As our research is problem-based, this descriptive and explanatory approach provides a pragmatic analytic framework around which to explore the complexity and challenge of delivering coastal slope management analysing the design, decisions, policies, institutions and stakeholder engagement.

Two study areas in the North-east Scotland (Fig.1a) were chosen to illustrate the problems associated with the instability of coastal slopes and the management of remediation both in the short- and long-term providing stability and resilience. Bervie Braes is a project where slope stabilisation funding was secured based on sufficient risk identified and where, through community engagement in the design and management of the stabilisation works, an innovative eco-engineering approach was delivered. Catterline Braes is a slope experiencing similar problems in the local area but represents a contested space where ownership and accountability for the risk amongst stakeholders has made securing funding difficult. This project has an active community who are keen to find a solution and to utilise the learning achieved through the Bervie Braes project. Published information was extensively studied and a number of site visits were carried out within a four-year period to monitor the processes occurring on both slopes and the management strategies applied. 13 semi-structured interviews with a range of stakeholders such as the Local Authority (LA), engineers, and members of the communities adjacent to the study sites were also conducted within this period with key themes emerging from the voices of the parties involved. Interviews were recorded, transcribed and then analysed using thematic analysis (Braun and Clarke, 2006).

2.1 Background of the Case Studies

2.1.1. *Bervie Braes (Bervie)*

Bervie comprises an 850 m long, 55 m high vegetated coastal slope west of the old harbour in Stonehaven, Aberdeenshire. The former trunk road connecting Stonehaven to Dunnottar Castle and A94/A957 road runs sidelong and generally NW-SE across the slope (Fig.1b). Around 60 residential properties lie towards the toe of the slope with the residents using the Braes for pedestrian access to the road and the nearby tourist attractions. The slope profile above the road is made up of a series of hollows, mounds, and bulges which represent washouts from ephemeral springs, material failed during one or more historical instability events (Table 1) and areas of ongoing creep respectively. On the slope below the road a visible seepage line is visible around the locations of former public wells used to provide drinking water for Stonehaven. The overlapping of old, apparently inactive, and active areas of slope instability gives the slope with its hummocky appearance (Currie et al. 2009). A watercourse runs from the agricultural land above the Braes down a gulley in the slope and was culverted beneath the road near the north-western end of the study area leading to the adjacent burn which, in turn, partly causes periodic flooding to the old town of Stonehaven.

2.1.2. Catterline Braes (Catterline)

Catterline is a 300 m long, 30 m high coastal slope forming the north-eastern end of Catterline Bay in Aberdeenshire, Scotland (Fig. 1c) located along the coast 10 km south of Bervie. Catterline comprises a series of exposed, mainly vegetated, slope sections interspersed with gully-outcrop forms ranging in height between 2 and 10 m. The slope is vegetated with a range of vegetation types including grasses, herbs, shrubs and planted trees covering the slope to a degree varying seasonally (approximately 20% in winter to approximately 80% during the vegetative period). A small tarmaced access road traverses the slope from south-west to north-east dropping in level towards the concrete landing stage on the north-east end of the bay. A gravel drain runs along the road discharging into the sea near the landing stage. Private residential properties are located along the crest of the slope with a grassed, non-fenced public footpath offsetting them from the slope. A branch of the footpath leads to a midslope structure – former pumping station used in the past for fresh water supply to the adjacent properties. A seepage line is visible adjacent to the pumping house, as well as 25 m north of the pumping house, indicating a series of springs with seeping water flowing along naturally formed gullies towards the gravel drain along the access road which, in turn, discharges into the sea at the landing stage which is used by the local diving club. Remnants of a sea wall defence comprising sections of rounded boulders, mass-poured concrete, anchored gabions, and concrete cubes exist at the toe of the slope and delineates the slope from the beach. The line of the sea wall is damaged to various degrees due to the action of the waves and seepage from the slope.

3. Results

3.1. History of problem and management at Bervie

Previous instability and erosion events on the slope (Table 1) were indicated to be the consequence of shallow groundwater, oversteepened ground profiles (Currie et al 2009) and extreme rainfall events. The Local Authority (LA) historically used traditional engineering measures to repair failures of the slopes adjacent to the road (Table 1) that they own. The Braes is owned by a charitable trust that has no direct funding for upkeep and maintenance of the location. The LA declined adopting the Braes from the trust due to potential risks associated with instability that would impact the residential properties at the toe of the slope. In 2010 the LA together with the Scottish Government raised limited funds to repair the damage to the road embankment following the most recent instability events in 2009 and decrease the risk of slope instability for the future. They appointed a geotechnical engineering consultant and involved the residents and the Community Council in the planning and design process (Mickovski et al 2013). Innovative stabilisation works including structural and eco-engineering stabilisation (Mickovski, 2014b) were completed in 2013 and the road partially reopened the same year for cars (one way) and pedestrians/cyclists. The eco-engineering methods employed included engineered planting and seeding of selected native vegetation in slope areas of lower risk of failure. This was supplemented by soil nails recessed into the slope and covered by bio-degradable pre-seeded soil mix in the areas of higher risk of failure. The design took into cognisance the potential climate change effects in terms of changes in temperatures and precipitation patterns and was chosen by the community at risk of instability (Mickovski, 2014a and 2014b).

Table 1. Timeline of instability events at Bervie Braes. (LA)-Local Authority, (R)-Residents

Year	Event	Consequence	Action (carried out by)
1958	Major slip above the south pier of the harbour	Collapse of a road section	Anchored sheet pile wall installed (LA)
1950s – 1970s	Drains and water supply channels blocked	Vegetation overgrowth	Burning vegetation on the slope at the end of the summer (R)
1980s	Slope failure at far western end	Major damage to residential property	Debris cleared, damage reinstated (R, LA)
1992	Distortion of the carriageway surface	Cracked pavement	Temporary single carriageway operation introduced (LA)
1993		Localised bulging of the slope and development of longitudinal cracking along the footpath on the embankment	Permanent closure of road in one direction (uphill) (LA)
1994	Slope failures above and below the road due to heavy continuous	Road blockage	Debris cleared; full road closure between February and July (LA)

	rainfall over a period of 4 days		
2009	Surface washouts and mud flows at the south-east end; major slip at the far western end	Undermined road embankment; major damage and abandonment of residential property	Full road closure; commissioning of a forensic study to determine the relationship between the local groundwater regime, including perched water levels, the locations of weak, sensitive soils and the movement and progressive failure of the road (LA)

3.2. History of problem and management at Catterline

Landslide activity along the slope (Table 2) has been historically linked to the springs, surface water flow, and areas of ongoing creep (Fig.2a). The LA reactively employed traditional engineering strategies for slope stability together with the residents albeit the slope has effectively no owner. Infrastructure belonging to water utility stakeholder is located on the slope, while no ownership of the seawall defence could be established. In the 1980s, the slope was owned by a trust founded by a resident but after the trust went into liquidation in the early 1990, the ownership status has not been resolved.

Table 2. Timeline of instability events at Catterline Braes. (LA) – Local Authority, (R) - Residents

Year	**Event**	**Consequence**	**Action (carried out by)**
1940	Slips at slope toe	Coastal erosion	Mass concrete and concrete block sea defence wall built along a section of the beach (LA)
1950s – 1970s	Drains (ditches) and water supply channels blocked	Vegetation overgrowth	Burning vegetation on the slope at the end of the summer by the residents; cleaning of the drain channels by the Local Authority (R)
1965	Slip at the crest of the slope	Mass wasting, buried existing well and pump on the slope	Manual clear up of the failed soil; extended sea defence wall by anchored gabions (R; LA)
1980	Sheet erosion of the slope	Surface water flow on the slope and access road	Drains trench built along the access road (LA)
1983	Debris flow	Mass wasting on the access road	Manual clean up; willows planted in a small section of the slope (R)
1994	Major slip at slope crest	Subsidence, soil mass wasting	Sheet piles installed to support ground in front of the house; attempt at ground investigation and monitoring (LA)
1995	Major slip at slope crest at the same location as in 1994	Subsidence, soil mass wasting; blocked drains	Excavation into the slope and installation of gabion baskets (LA)
2000	Slip at slope crest near the entry to the access road	Blocked access road	Slope re-graded and anchored geotextile installed (R)
2005 – 2012	Slip along the embankment of the access road	Subsidence of a section of access road; cracking in the pavement; drains dysfunctional	Subsided areas ‘topped up’ with tarmac and surface water directed over the pavement and into the embankment (LA)
2013	Damaged sea wall defence and slips of the slope behind the wall	Subsidence of the access road, mass wasting and erosion of soil behind wall	Reinstatement of the damaged concrete blocks; attempt at ground investigation on the slope (LA)

During a storm in 2013, high waves topped the seawall, eroded the lower slope and overturned and dislocated sections of seawall defences. This collapse allowed the movement of the soil on the slope (Fig.2b) which resulted in subsidence of the access road embankment. It is possible that this failure could migrate upslope and lead to further instability, potentially affecting the properties at the crest. After this event, the local community asked for help from the LA who due to limited budget and perception of low risk, commissioned an earthworks contractor to repair the road and reinstate the seawall which got damaged by the sea action later the same year, leaving large portion of the slope toe exposed to the waves. The local community then started to look for help and assistance elsewhere to minimise the risks to their property and life. An innovative approach based on the lessons learned from Bervie to see at least mitigation of the current instability is currently sought by the community. The use of such approach would be aimed at employing eco-engineering strategies, such as the sustainable use of vegetation, to provide erosion protection and resistance against shallow landslides. This can be combined with structural stability measures in the areas of highest risk of instability (Mickovski, 2014a).

4. Analysis and Discussion

4.1. Innovative design and management

The analysis of the history of problem and management showed that the case study sites have similar geology, climate, and environment, which allows the innovative design and management of stabilisation measures and experiences at Bervie to be used at Catterline to minimise the risks and provide resilience. The risk of shallow and deep failures as well as erosion and flooding associated with the effects of climate change (Mickovski 2014b) exist at both sites and affect the residential properties and infrastructure alike. At Bervie (Fig. 3a), the resistance to catastrophic landslides is provided by soil nails and a reduction in erosion and increased resilience with easier recovery from any potential shallow slips is provided through sustainable use of vegetation. The same approach could be modified at Catterline where a new or repaired and enhanced seawall defence (Fig. 3b) could be designed to adapt to climate change impacts and combined with eco-engineering strategy that will mitigate the effects of historical instability on the slope in order to provide resilience in the long term. Additionally, based on the interviews with the communities at both Bervie and Catterline, the resilience in the short term and sustainability benefits (e.g. provision of recreational space) could be provided for Catterline in terms of design for reliability and durability by taking into account the changing role of vegetation in erosion protection and slope stability at various temporal scales (Tardio and Mickovski, 2016; González-Ollauri and Mickovski, 2014). This innovative solution has an added sustainability value in terms of minimal maintenance in the long term. Also, it would increase the recreational value of the coastal slope such as pedestrian or cycling access to tourist attractions at Bervie and local fishermen and diving club at Catterline.

For innovative solutions to be delivered which reflect the complexity of the risk and slope, local needs and financial constraints, the conditions for creativity need to be in place but significantly management support is required for its implementation. In both projects, an important component was the discourse between the stakeholders, ensuring that they were receptive to ideas, informed about the potential risks, and responsive to the construction and maintenance plans for the slope. The inclusive nature of the projects promoted a culture which was capable of supporting a creative design process, but also aided to achieve mediation, learning and a trust in the engineer's technical judgement. The varied nature of the engagement approaches were important with a mix of face to face meetings, informal discussions, community public meetings, and a fly-by presentation to visually represent the design to the community. Building relationships, establishing trust and enabling openness during discussions helped the designers to reflect local knowledge but also facilitate community understanding and acceptance of the proposals and their implications (for construction phase disruption and long term). In the early stages of a project this not only informs its development but aids the creativity process required for innovation in design, which otherwise may not have been possible. However, if wrongly managed, the potential exists for engagement to act as a barrier to innovation. The radical nature of this solution would be reduced if, for example, the stakeholders and wider community lack trust in the engineering team, there is uncertainty over the risk presented or if too much effort is required to make a decision.

The approach of integration of a slope stabilisation project within a risk management framework could be implemented at Catterline based on the promotion of experiential learning from Bervie (Fig. 4). This would be a change from the way these problems have been managed in the past (see Table 1 and 2) and in line with the current (trans-)national planning strategies. This shift reflects the new paradigm advocated for managing environmental projects within the current policy context which encourages stakeholders to reflect and learn lessons from the past and other projects in order to help facilitate solutions based on innovative practice. In the case studies this was done using the close proximity, sharing of knowledge and experience between the stakeholders through informal and formal mechanisms such as local meetings and the sharing of expertise with the consistent stakeholders including the design engineer.

4.2 Sustainability and risk

Reflecting the current state of management of unstable coastal slopes in Scotland, the two case studies showed that risks to life and property were the main drivers for actions leading to stabilisation but identified site ownership and funding for works as constraints in the process. The ownership status of the sites presented limitations which without community leadership could stall the project due to uncertainty. At Bervie the LA took ownership of the slope failure risks due to historical ownership of the road on the slope and the stabilisation works were procured. Catterline is a contested space with only the water authority owning assets but it has not engaged in consultation to date. Furthermore, in the absence of a risk owner the community is forced to explore sources of funding for stabilisation works as a community project. In developing a community project, ownership problems can be overcome if a case for reducing risk, building resilience, and aiding the common good can be established as a basis for funding applications (Astley-Reid et al. 2013). Supporting communities to self-organise and represent themselves as they see fit is important, and evidence suggests it permits discourse and representation which is appropriate and meaningful (Manzo and Perkins 2006). Such support would be important to facilitate intervention when appropriate, but also to support community dialogue over the implications when controlled slope failure is the best perceived course of action. However, communities would be facing real and difficult challenges if they are to sacrifice (abandon) property or infrastructure and the decisions to be taken would require knowledge, self-organisation and mediation of views.

The limited funding raised at Bervie precluded stabilisation of the whole slope below and above the road. The Engineer had to further assess the risks of instability and prioritise areas for stabilisation, resulting in stabilisation of 60% of the slope below the road. The rest of the slope is remotely monitored and stability re-assessed during/after any critical rainfall event as part of the Emergency Plan developed by the LA and the Engineer in cooperation with the residents. At Catterline, the community managed to cover approximately 40% of the slope with planting more than 850 trees and shrubs in priority areas as specified by the Engineer through grants from the Woodland Trust. This demonstrates that community leadership plays a significant role in promoting involvement in the design process, aiding the local needs reflection and arriving at an appropriate solution which reflected the perceived risk and funding context. However, long-term monitoring and emergency planning at Catterline will depend on research interest from the academia and the motivation of the residents due to lack of funding.

This approach will have implications on the current standards and codes of practice which will have to be synchronised to allow implementation. Because of the multi-disciplinarity of such projects, a possibility of this type of design framework will have to be included in the standards/codes of practice for environmental and spatial planning, geotechnical and hydrological engineering as a minimum. The inclusion in the codes of practice may be facilitated with the development of specific Key Performance Indicators for recording and monitoring sustainability of such projects (e.g. Environmental Geotechnics Indicators; Jefferson et al. 2007)

4.3. Stakeholder engagement

Both case studies demonstrated that projects which are inclusive of stakeholders at a strategic, project, and community levels enhance evidence provision aiding the awareness, identification and understanding of the risk presented. This facilitated the consideration by engineers of suitable design solutions, and when shared with the community this promoted discourse, mediation of views, their input to help evolve the design and ultimately acceptance (Mickovski 2014a,b). The discourse between the stakeholders at Bervie ensured that they were receptive to ideas (e.g. move away from the traditional reactive engineering in order to provide sustainability value for the community represented in the decision making), informed about the potential risks, and responsive to the construction and maintenance plans for the slope (e.g. community pressure to re-open the road with a cycling lane in response to the known risks while given the opportunity to report any maintenance issues directly to the Local Authority). These could not be achieved at Catterline due to a non-responsive stakeholder. The inclusive nature of the Bervie project promoted a culture which was capable of supporting a creative design process, but also aided to achieve mediation, learning and a trust in the engineer's technical judgement. On the other hand, the engagement of the community in Catterline with academia (e.g. establishing a community liaison with academia and industry) led to external charitable funding allowing design and construction of preventive measures as well as training (e.g. workshops) in monitoring and managing the slope.

The varied nature of stakeholder engagement approaches at both study sites were important with a mix of face to face meetings, informal discussions, community public meetings and presentations to visually represent the design to the community. Levels of engagement were observed in the interviews with parties form both sites to be significant compared to similar projects due mainly to strong self-organisation, interest and a willingness to be involved. On the other hand, building relationships, establishing trust and enabling openness during discussions helped the engineers to reflect local knowledge but also facilitated community understanding and acceptance of the proposals and their short- and long-term implications. In the early stages of a project this not only informs its development but aids the creativity process required for innovation in design, which otherwise may not have been possible. At Bervie, the Engineer and LA demonstrated motivation and desire to innovate and develop new stabilisation and management solutions to accommodate the budgetary constraints.

4.4. Double loop learning

The stakeholder engagement resulted in a set of experiences structured in such a way that lessons learned were an opportunity to improve further similar experiences. This marks a shift from the dominant single loop style of learning which restricts stakeholders to learning from problems which arise through its reactive mindset (Stienfuhrer, 2009). The recent shift in risk management within the environmental context calls for stakeholders to adopt a more reflective approach where a wide variety of evidence is evaluated with a view to learning lessons and considering these even before problems arise (Wedawatta et al., 2014). The residents at Catterline reported the benefits of the learning process based on the experiences at Bervie transferred through meetings between the members of each community, the involvement of the same Engineer and the LA while being directly involved in the design and management processes. On the other hand, the Engineer and LA, together with other stakeholders involved in these projects benefitted from the local experiences and knowledge which helped in identifying the problem and potential solutions, and creating possibilities for translating these to similar circumstances elsewhere (e.g. Catterline) as experiential learning (Yin, 1994) (Fig. 4).

The approach to managing the coastal slopes in both of the case studies (Fig. 4) highlights the need for a dynamic learning environment which ensures that the lessons learnt are carried forward by all stakeholders as they reflect on the project. A key characteristic to promoting this environment is for a project team, stakeholders and the community to be willing to explore ideas and solutions in an open and transparent manner. This led to solutions which were tailored and accepted for the local context. The Bervie case study reflects an environment which gets close to this with the evolution of the design aided by an inclusive culture (e.g. community engagement through all stages of the project including selection of a stabilisation option and development of monitoring and risk assessment procedures for the long-term) which promotes an exchange of knowledge and opportunities for social and mutual learning. The Catterline case study demonstrated a team who recognised the benefits of providing space for creative thinking and worked with stakeholders (project and community) to achieve implementation. In the latter case, the community established a long term management practices such as development and maintenance of drainage networks, planting and maintenance of planted material, and monitoring of the overall stability. Interviews revealed that realising double loop learning within the design stage and management of stabilisation projects is not reflective of wider practice. Its value within the Catterline project was highlighted by the delivery of an innovative solution within a project which lacks the same level of public attention or pressure for a solution as at Bervie.

The research revealed the importance of intra-project knowledge sharing and learning. This takes place across the project stages and is evidenced by involvement of the team and community in the design, construction, and maintenance of the slope within both case studies. The exchange of knowledge between the projects through a range of expert and informal mechanisms also highlighted the benefits of inter project knowledge sharing and learning. Bervie Braes due to its funding position was able to acquire the expertise in a design engineer and contractors able to provide the latest eco-engineering solutions. Catterline Braes due to its limited access to funds would have ordinarily been unable to access expert knowledge. However, due to its close geographical proximity, many of the same stakeholders and community networks as well as the willingness of the design engineer from Bervie Braes to work with the Catterline Braes stakeholders, it was possible for an innovative design to emerge. The design engineer viewed the extension to work with Catterline Braes as part of his development forming the basis of academic research. It presents an evidence of expert but also experiential learning which facilitates the double loop learning. Active communities who are engaged in the long term development of the slope has been influential in promoting a practice learning culture and this is evidenced by their involvement in its maintenance promoting a genuine community interest for the slopes.

5. Conclusions

In conclusion, our research showed that the awareness of the risks, potential solutions and mechanisms of funding is critical in the initial stages of a community project. Evidence shows that an engaged community has a better potential to find solutions within limited funding regimes based on an understanding of the risks and willingness to accept change once the risk ownership is clear. This can promote innovation in design but it can also, if the community or stakeholders are not engaged, stifle innovation. Our research showed that when communities recognise the value and need for intervention to ensure the long term resilience of a slope to climate change, they can be empowered to contribute to the case for securing public funds (Bervie Braes) or seek the expertise and knowledge to maximise limited resources (Catterline Braes). When intervention is recognised as a necessity this research shows that knowledge sharing between academia, industry and community in regional, national, and international context should be encouraged in the management of coastal slopes because the particular technical solutions often can be site-specific but the generic design and management principles can have a wider application and trans-boundary significance.

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Figure captions

Figure 1: a) Location of the study sites. General arrangement and instability characteristics of the coastal slope in b) Stonehaven (Bervie), and c) Catterline. Source: Google Earth, 2014.

Figure 2. (a) Shallow translational slides and mudflow and (b) deeper slides behind the seawall defence.

Figure 3. Integrated engineering solutions that a) was applied at Bervie b) could be applied at Catterline.

Figure 4. Proposed stabilisation and management framework in the context of risk and learning as used at the case study sites.